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Title: High-Resolution 3D Acoustic Borehole Integrity Monitoring System

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High-Resolution 3D Acoustic Borehole Integrity Monitoring System

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Los Alamos National Laboratory

U.S. Department of Energy

National Energy Technology Laboratory

Addressing the Nation's Energy Needs Through Technology Innovation – 2019 Carbon Capture, Utilization, Storage, and Oil and Gas Technologies Integrated Review Meeting

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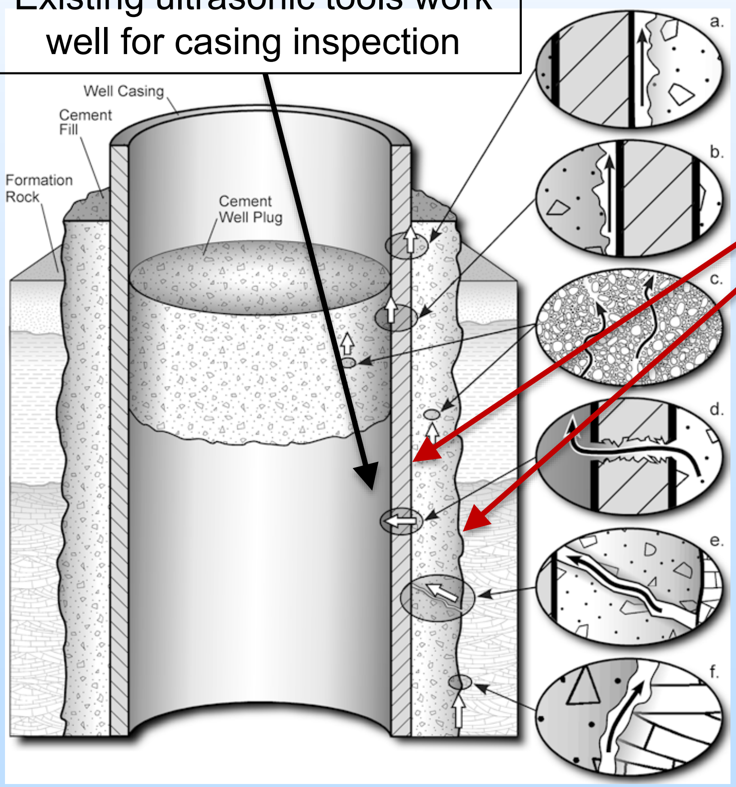
Presentation Outline

- Technical Status
- Accomplishments to Date
- Synergy Opportunities
- Project Summary

Technical Status

Develop a high-resolution 3D imaging system for improved wellbore diagnostics and integrity assessment

Existing ultrasonic tools work well for casing inspection



** Picture from S.E. Gasda, Environ Geol (2004) 46: 707-720*

Extend applicability to: (1) casing-cement interface, (2) cement-formation interface, and (3) out in the formation (up to ~ 3 meters).

Performed a comprehensive literature/existing technology study for wellbore integrity monitoring tools.

Comparison of existing techniques and the present approach

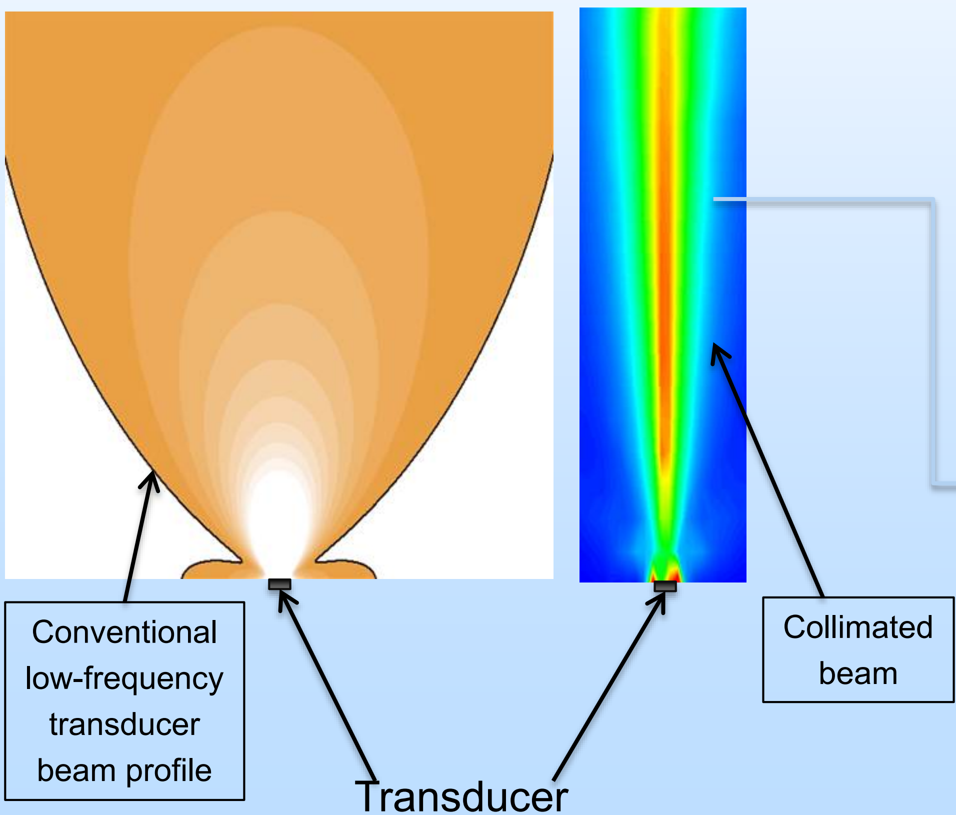
Method	Frequency (kHz)	Range (m)	Resolution (mm)
Sonic probe	0.3-8	15	~ 300
Present approach	10-150	~ 3	~ 5
Ultrasonic probe	>250	casing	4-5

Technical Status

The Proposed Approach:

Novel technique that fills this technology gap.

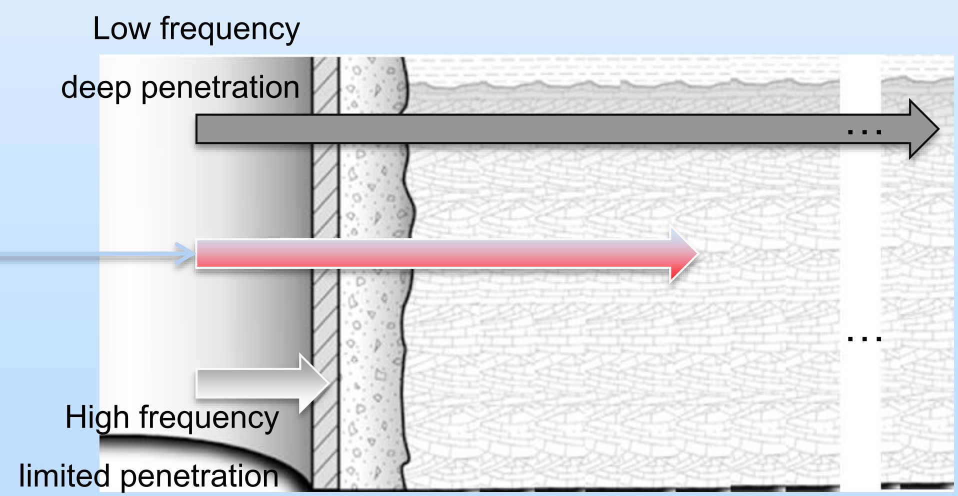
1. Collimated beam for increased resolution



2. Low frequency for deeper penetration

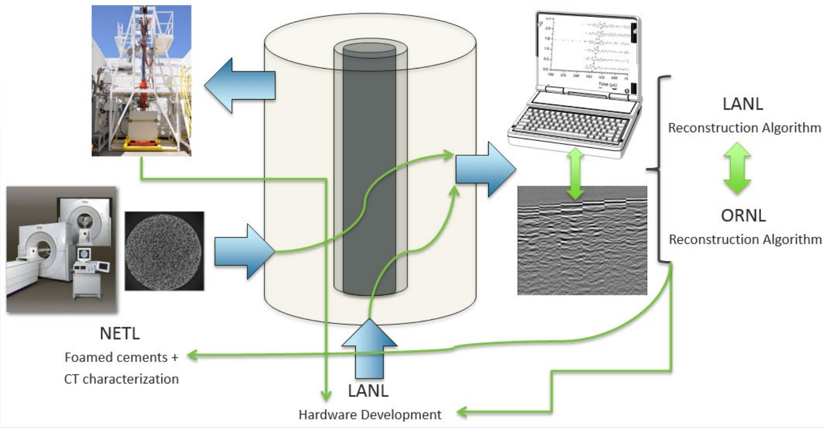
$$\textit{Attenuation} \sim f^n$$

f = frequency, n = 1-2



Technical Status

Multi-lab project



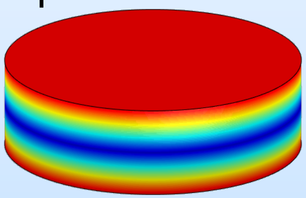
Inter-lab collaboration and teaming arrangements/partnerships

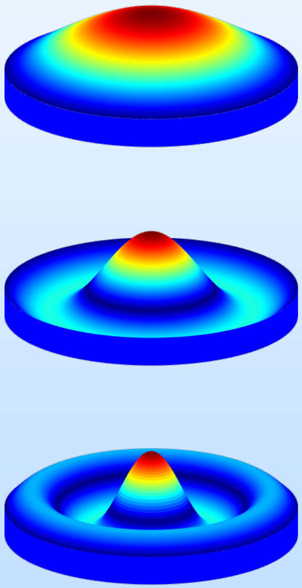
- Develop acoustic source, imaging system, and image processing.
- Investigate acoustic metrics for foamed cements. Incorporate new metrics for wellbores in the field.
- Explore different image processing approaches.
- Perform experiments in more realistic boreholes. Incorporate data from realistic borehole and compare resolution with lab experiments.

Technical Status

(1) Generate collimated beam by exciting radial modes of piezoelectric disk
(2) Clamp disk edges to focus energy into collimated beam

Traditional acoustic source
“piston mode”



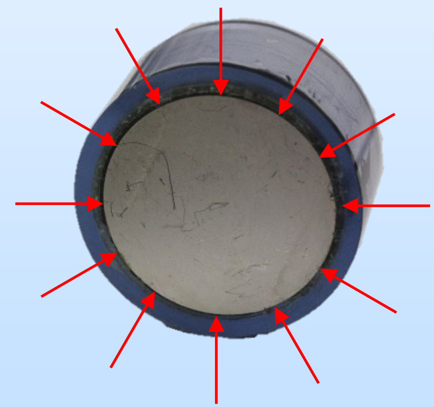


Radial mode 1

Radial mode 2

Radial mode 3

Clamped piezoelectric disk



Technical Status

(1) Generate collimated beam by exciting radial modes of piezoelectric disk
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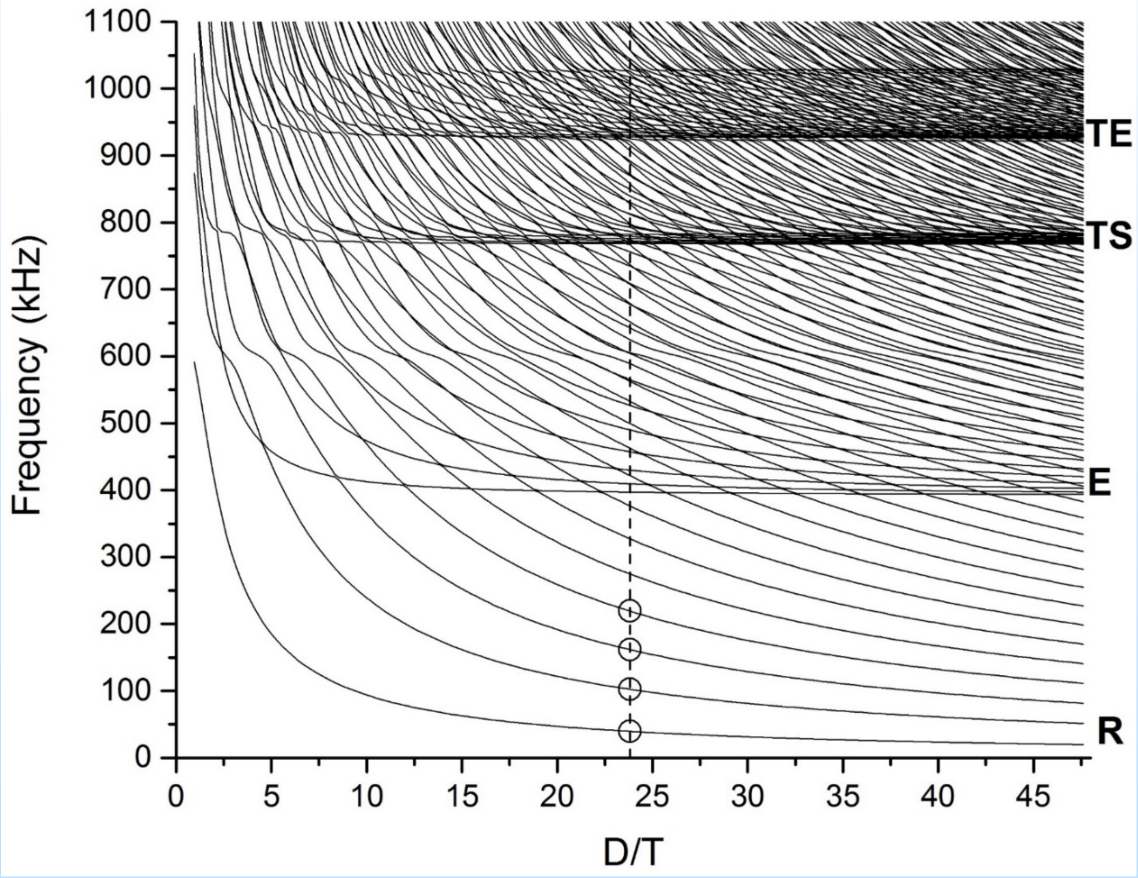
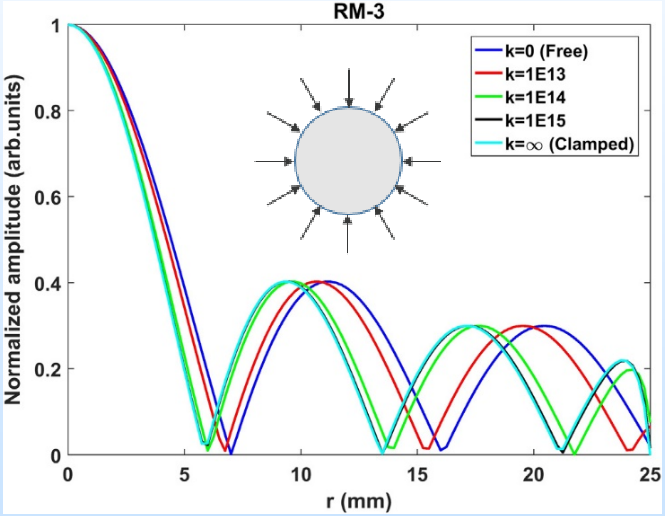
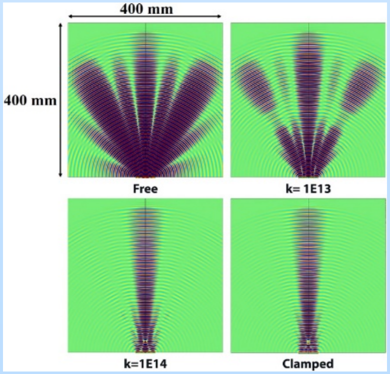
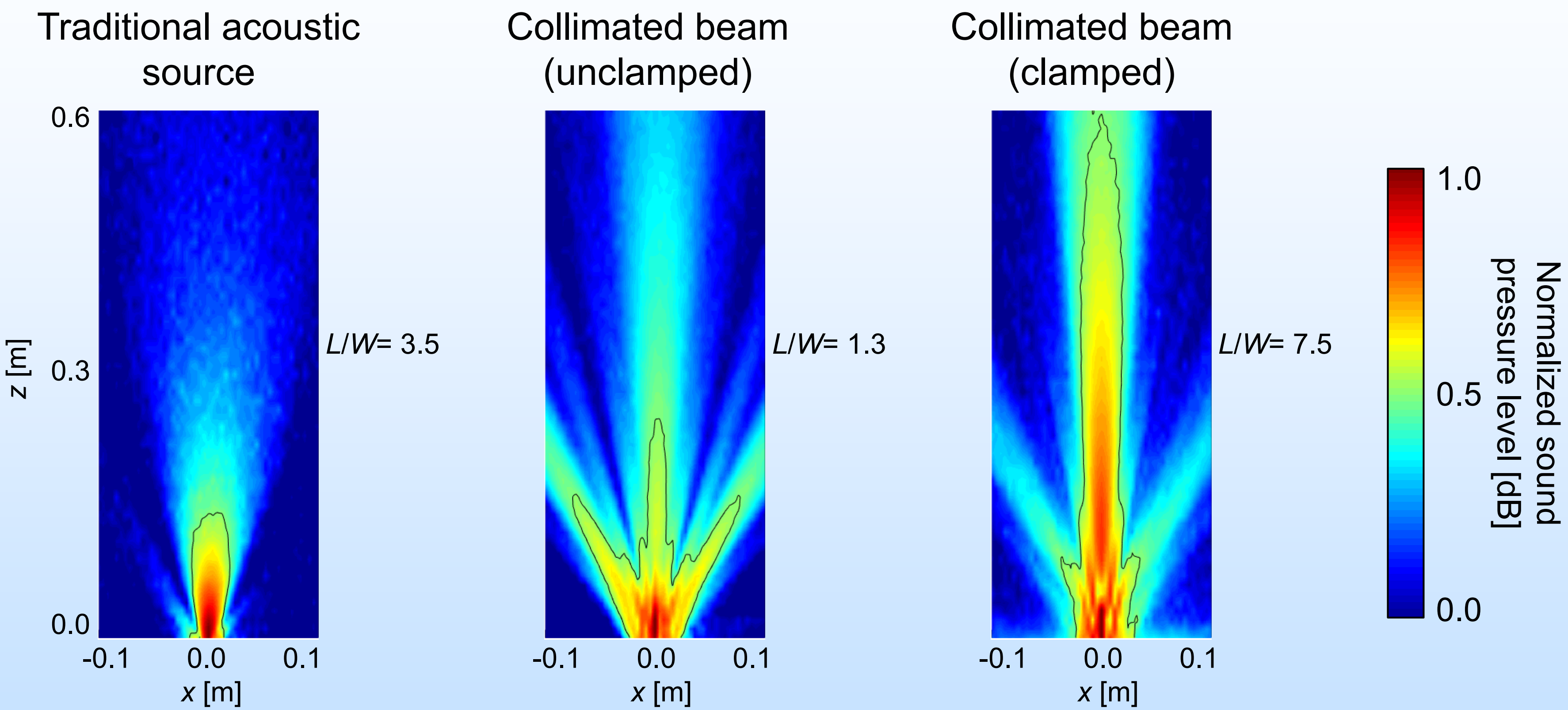


Normalized out-of-plane displacement on the surface of the disc for RM-3 for different lateral stiffness k (N/m3)





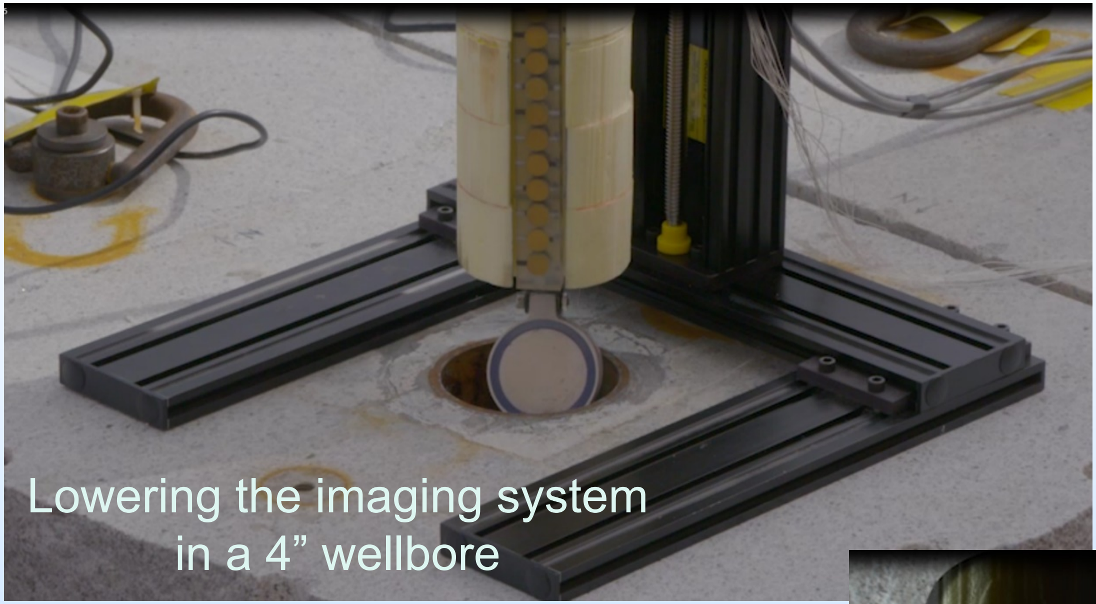
Technical Status

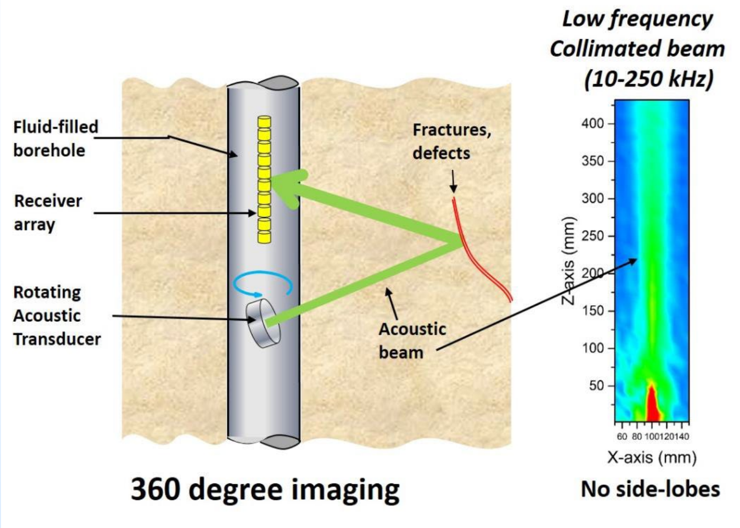


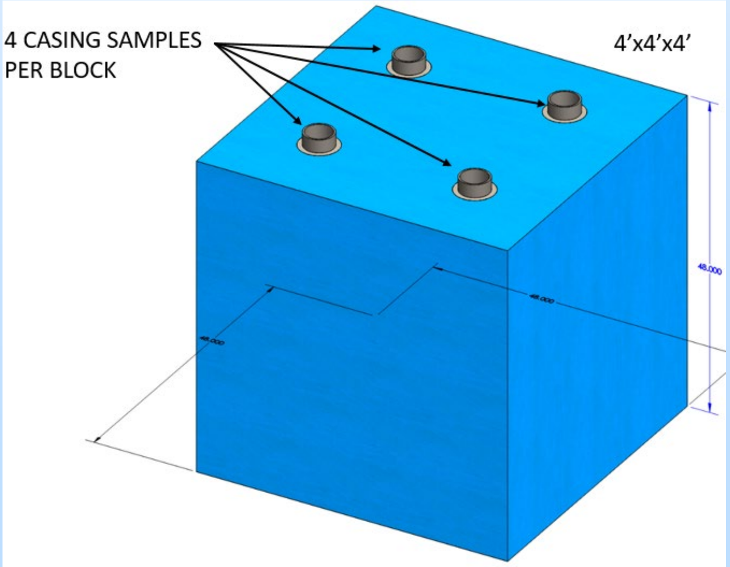
Collimated beam provides:

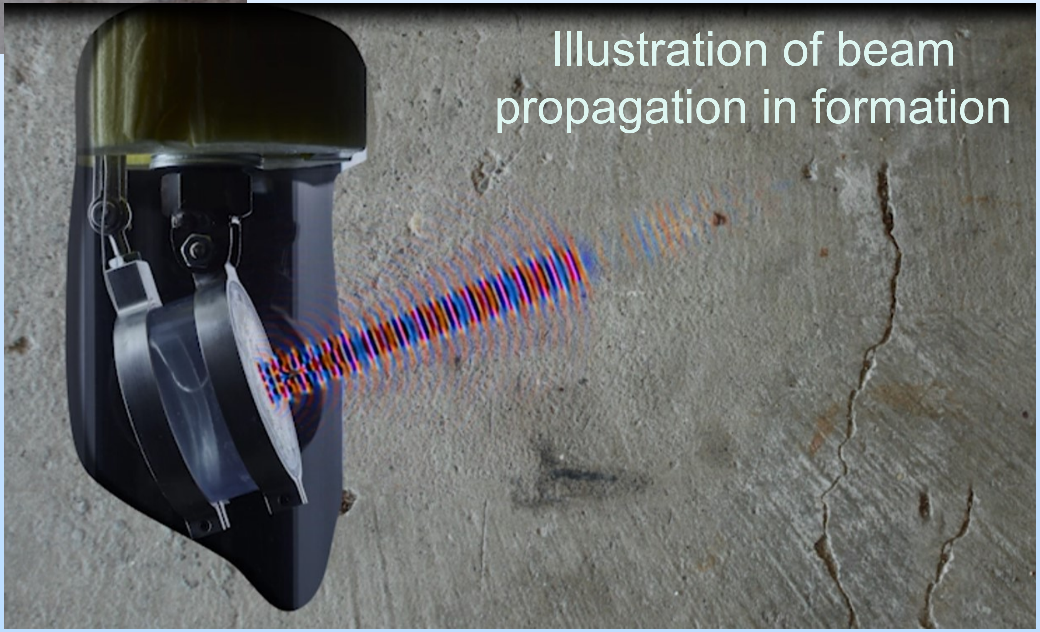
- Reduction in beam width → higher image resolution, more control over directivity
- Increased beam length → longer detection/communication range

Technical Status



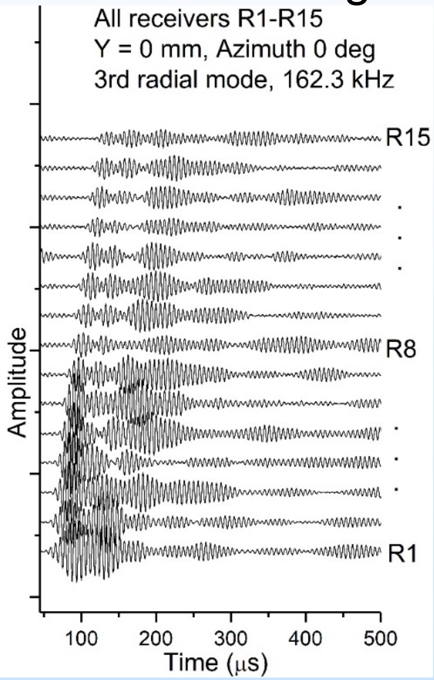


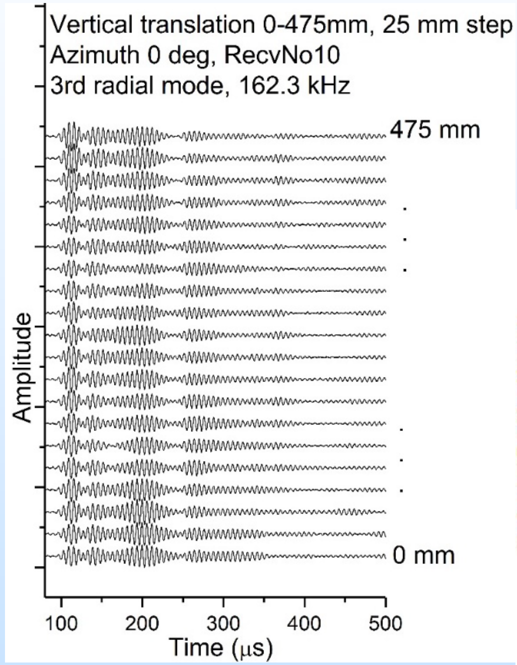


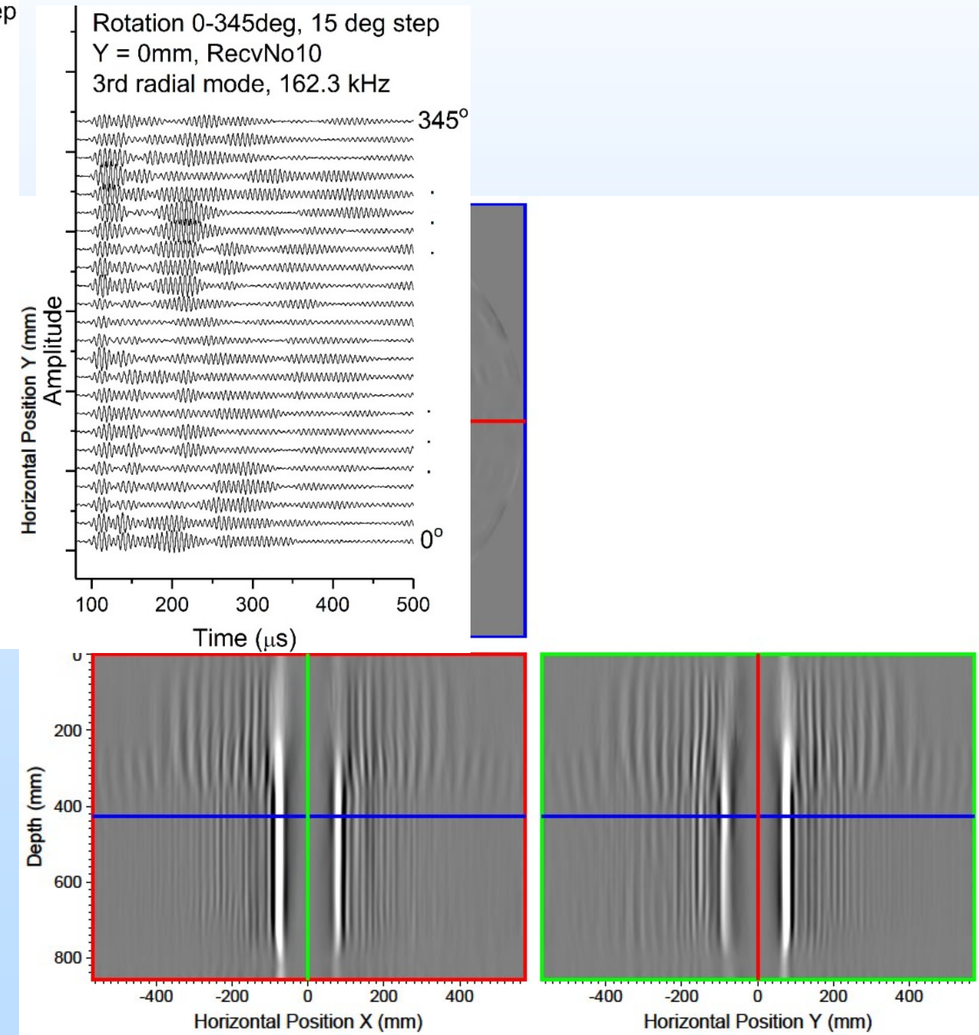


Technical Status

Performed scans on granite blocks
360 deg rotation, and 475 mm vertical span, 5 deg and 25 mm step size

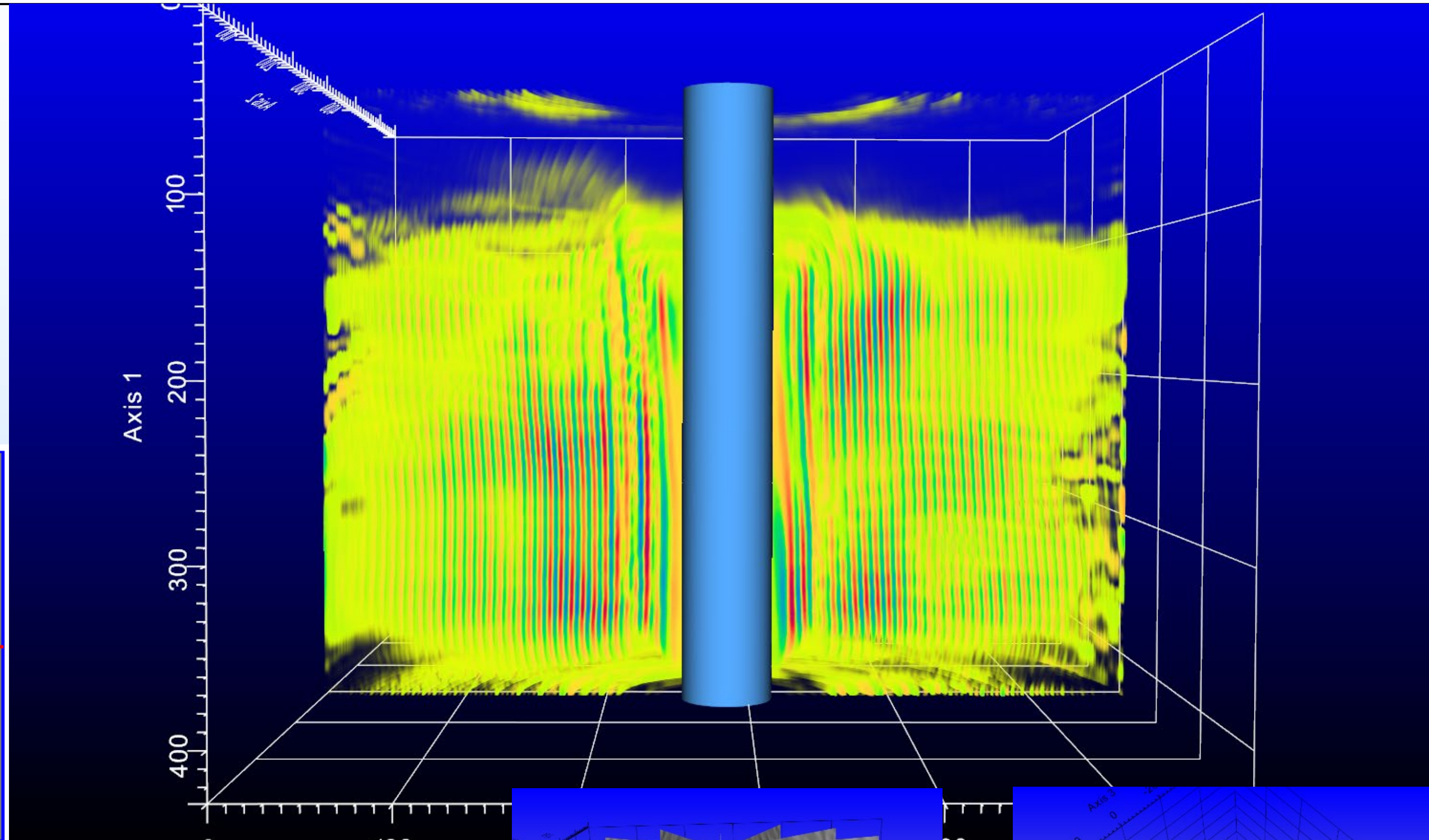


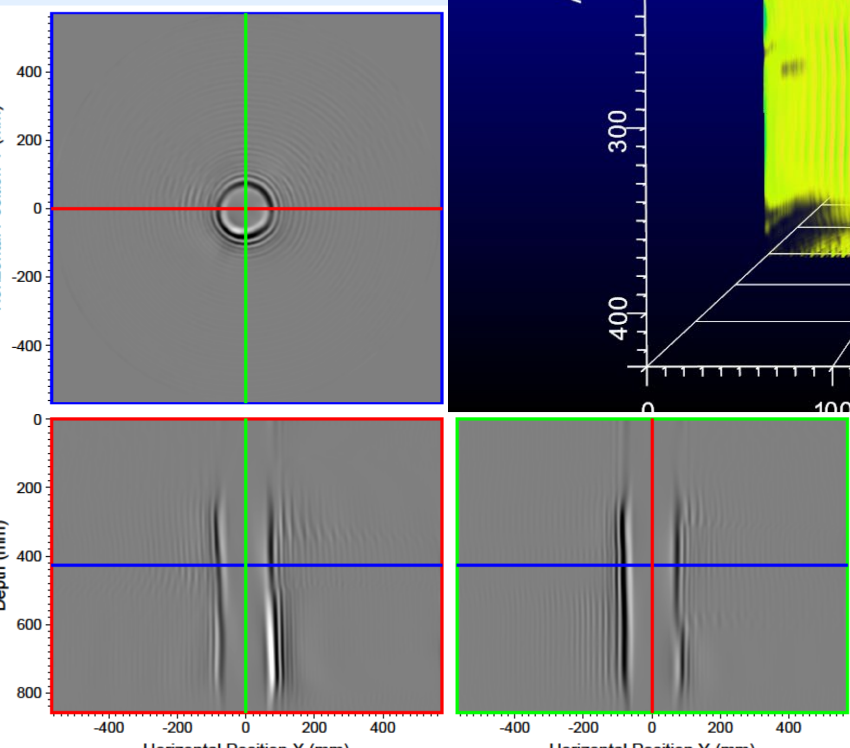


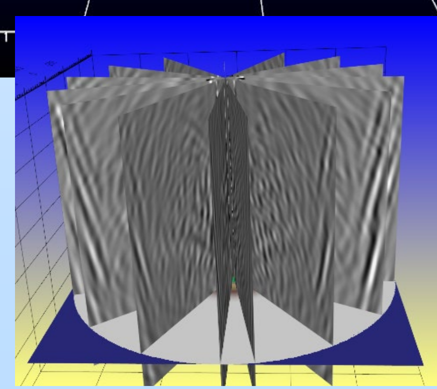


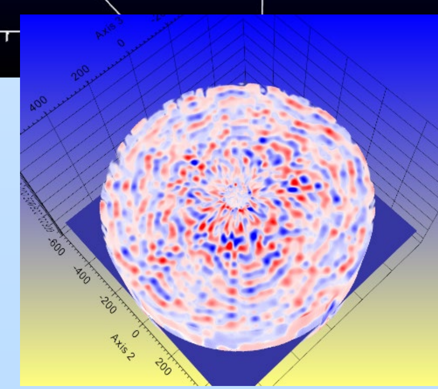
Technical Status

Block III
Eccentricity – lean
from N to S





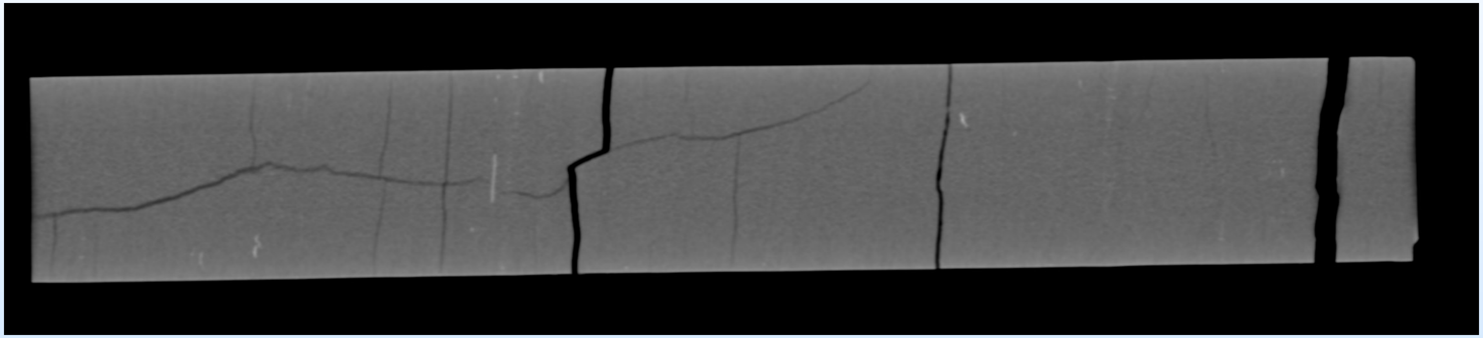


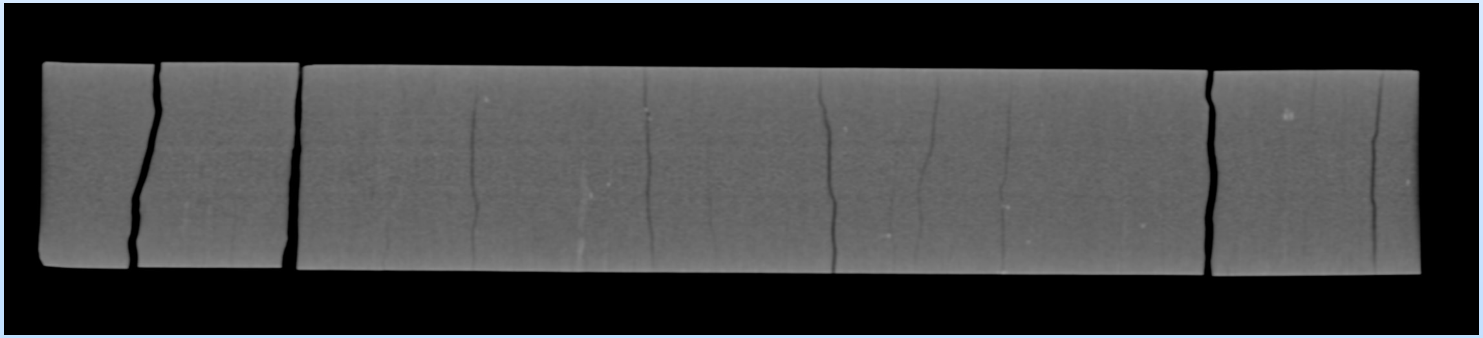


Technical Status

Acquired two samples of Mancos Shale with the following dimensions: 19 in OD
36 in tall
6 in borehole

Mancos Shale cores - CT scans:

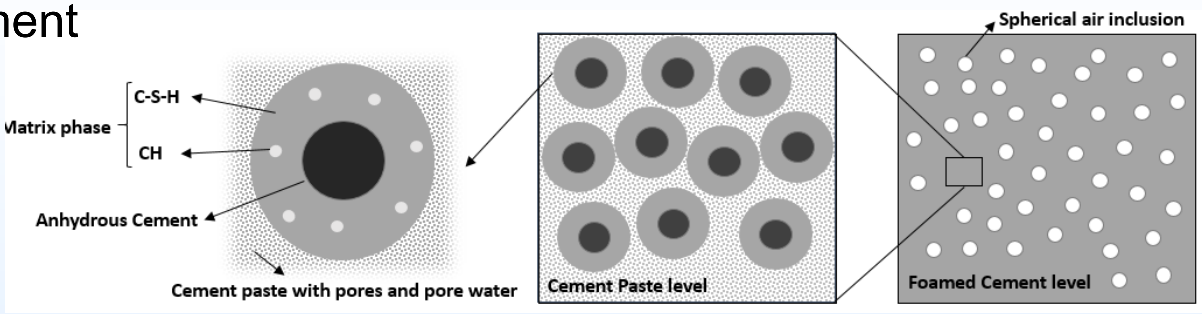




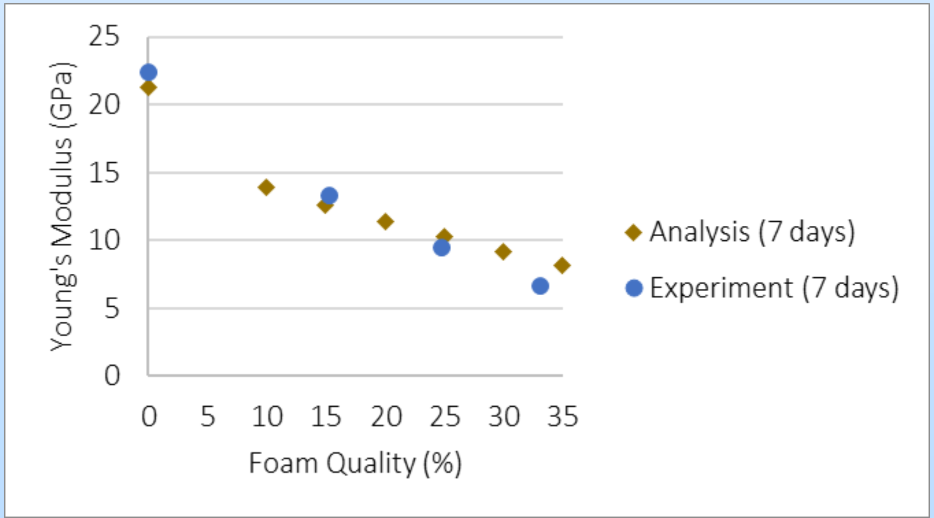
Working on procedure for cementation of 4” steel casing in foam cement.

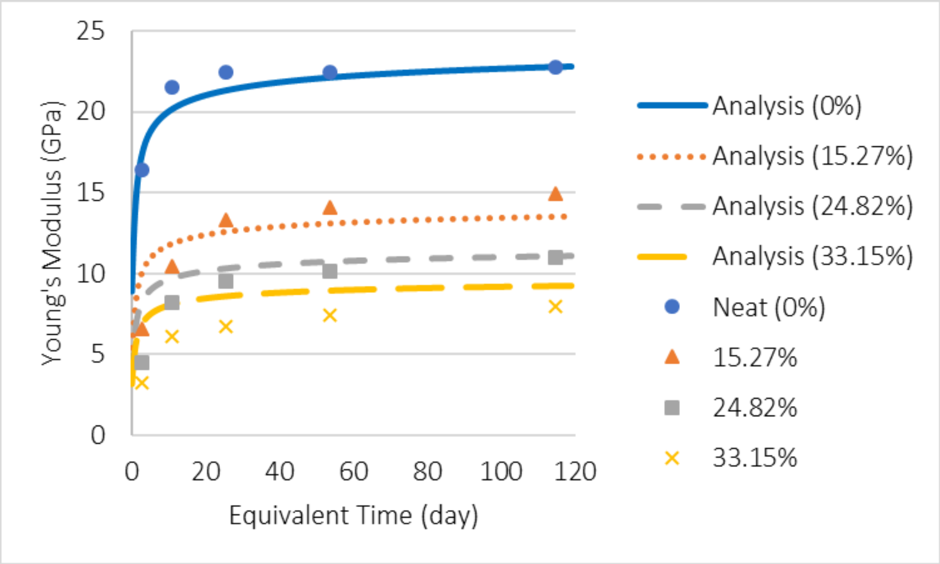
Technical Status

- Heat of Hydration Measurement
- Activation Energy
  - Neat cement: 37.5 kJ/mol
  - Foam cement: 35.6 kJ/mol
- Hydration modeling
- Mechanical properties



- The effective medium theory was used to calculate Young's modulus of cement paste and foamed cement with different foam qualities.
- Both analytical and experimental results show that the Young's modulus tends to reduce as the foam quality increases.



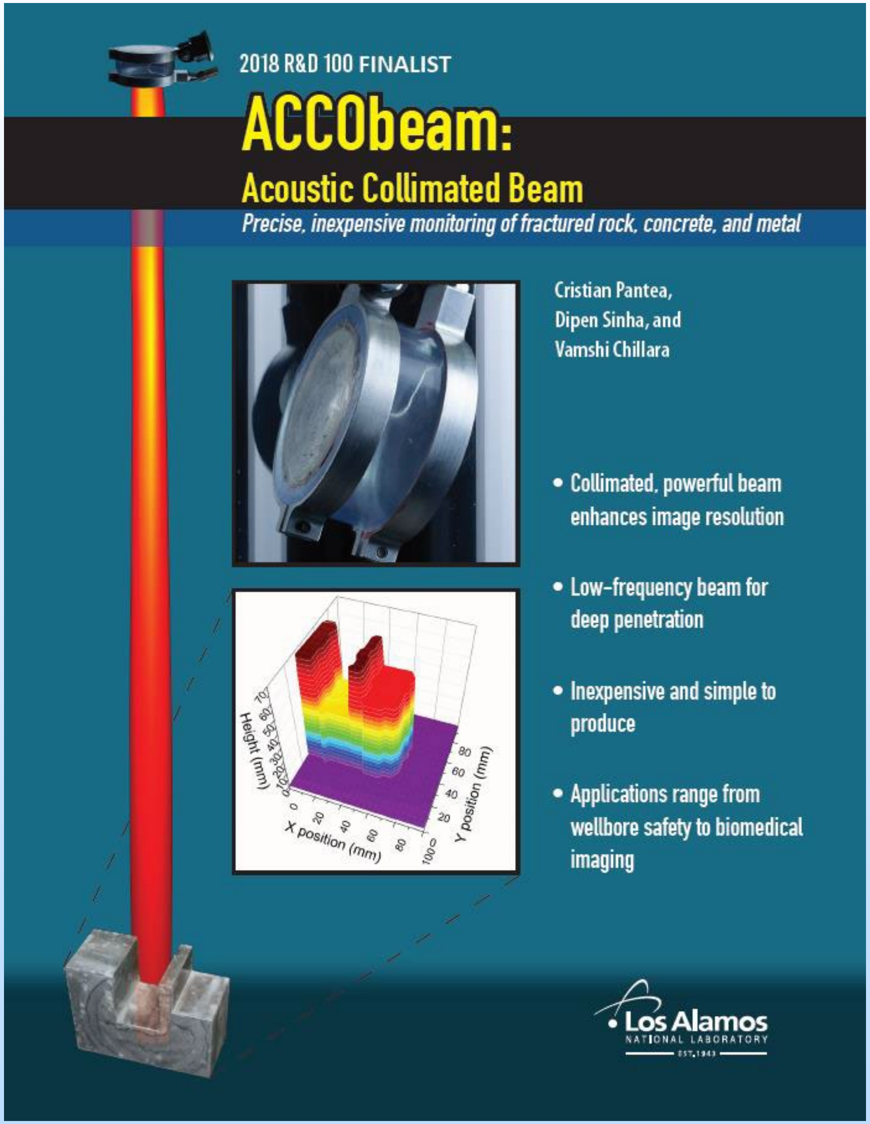


	0%	10%	20%	30%
ρ(g/ml)	2.0631	1.7481	1.5510	1.3791
Air%	-	15.27%	24.82%	33.15%

Accomplishments to Date

- Performed a comprehensive literature/existing technology study for wellbore integrity monitoring tools
- Refined hardware (ACCObeam – Acoustic Collimated beam)
- Refined software for faster measurement and analysis
- Performed theoretical prediction and experimental measurements on foamed cement elasticity with different hydration degrees
- Acquired data in granite with embedded defects (wall thinning, casing eccentricity, channeling, delamination)
- Data analysis for the above – in progress.
- Planning cementation of 4" casing in two samples of Mancos shale

Accomplishments to Date



Publications

- Ultrasonics, 2019,vol. 96, no. 7, pp. 140-148.
- AIP Conf. Proc., 2019, vol. 2102, pp. 040013.
- Appl. Phys. Lett., 2018, v. 113, issue 7, p. 071903.
- Wave Motion, 2018, vol. 76, p. 19-27.
- Appl. Phys. Lett., 2017, v. 110, issue 6, p. 064101
- Proceedings of SPIE, 2017, v. 10170, p. 1017024
- *2 more papers submitted*

Conferences

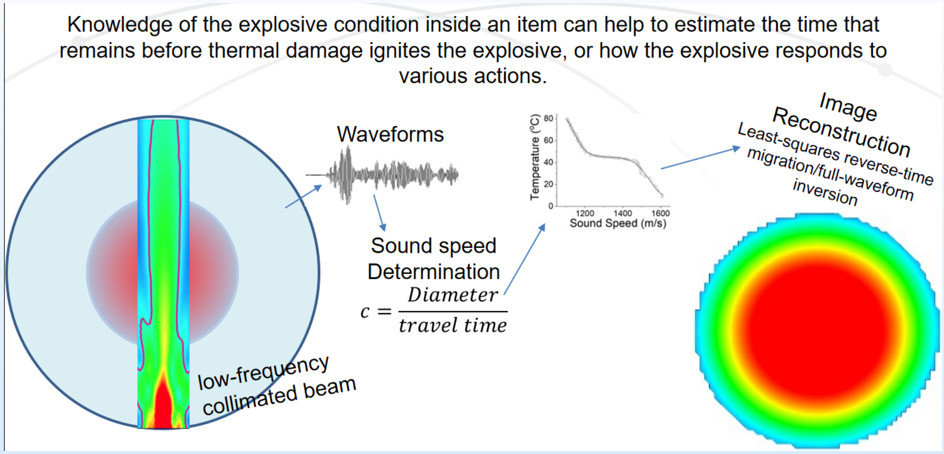
- 177th Meeting of the Acoustical Society of America, 2019
- The 2019 IEEE International Ultrasonics Symposium (IUS)
- 52nd U.S. Rock Mechanics/Geomechanics Symposium, 2018
- Sixth International Congress on Ultrasonics, 2017

IP

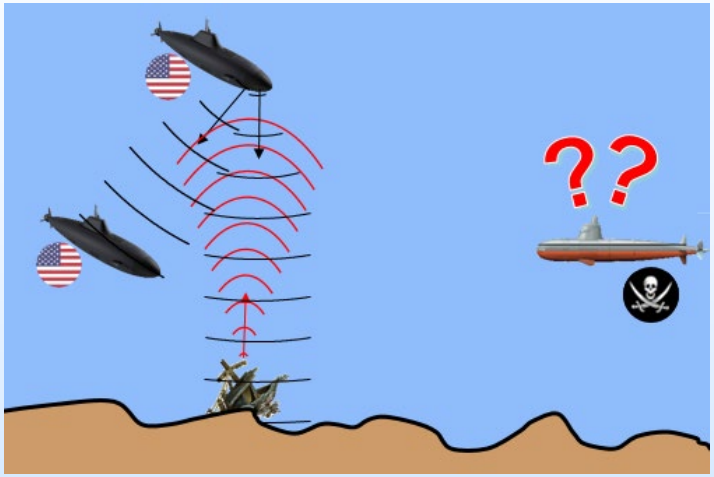
- 1 patent application (Resonance-based Nonlinear Source)
- 1 patent application (Bessel-like Acoustic Source)
- 1 provisional patent (Imaging Technique with Low-frequency Beam)

Synergy Opportunities

3DHEAT (high explosive acoustic temperature)



Underwater communication



Possible future collaboration identified in several different areas of interest to the CO_2 sequestration/FE community:

– Hydraulic Fracturing/Simulation Diagnostics

– Intelligent Monitoring Systems, Well Integrity and Zonal Isolation

– CO_2 Storage

Project Summary

- Key Findings:
  - There are no commercial acoustic sources that provide a collimated beam over a frequency range of 10–250 kHz in a small package that works in different media
  - Developed improved acoustic source, significantly more powerful than its predecessor
  - Enhanced receivers sensitivity
  - Developed robust operation software, speeding up data collections
  - Investigated materials choice for harsh environments

- Next Steps:
  - Further refine acoustic source for deeper penetration
  - Image processing and technique refinement for faster collection/analysis
  - Enhance capabilities for foamed cements

Appendix

– These slides will not be discussed during the presentation, but are mandatory.

Benefit to the Program

- Program goals being addressed:
  - Develop and validate technologies to ensure 99 percent storage permanence.
  - Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness.
- Project benefits statement:

The research project is developing a Borehole Integrity Monitoring System to reduce the risk of release of CO_2 around the well casing and cement. The technology, when successfully demonstrated, will provide an improvement over current wellbore diagnostics and integrity assessment techniques. This technology contributes to the Carbon Storage Program's effort of improving reservoir storage efficiency while ensuring containment effectiveness.

Project Overview

Goals and Objectives

- Project goals and objectives in the Statement of Project Objectives.
  - The main objective of this project is to develop a high-resolution 3D imaging system for improved wellbore diagnostics and integrity assessment, with the ultimate goal to develop a commercially deployable technology.
  - Wellbore integrity monitoring and characterization of the near wellbore environment are in need of novel technologies for better, faster and safer characterization methods. Some of the goals of these methods are: (1) improved resolution, (2) extended characterization range, and (3) in-situ/real-time monitoring. We are planning to work in parallel to address all these three requirements, such that we can provide a complete solution for wellbore diagnostics and integrity assessment.

Project Overview
Goals and Objectives

- Project goals and objectives in the Statement of Project Objectives.
  - How the project goals and objectives relate to the program goals and objectives:
    - We are looking into providing a complete solution for wellbore diagnostics and integrity assessment. As mentioned on a previous slide, this technology contributes to the Carbon Storage Program's effort of improving reservoir storage efficiency while ensuring containment effectiveness.

Project Overview

Goals and Objectives

- Project goals and objectives in the Statement of Project Objectives.
  - Identify the success criteria for determining if a goal or objective has been met:
    - Identified and assessed existing commercial technology.
    - Determined resolution for channeling outside casing.
    - Performed successful tests on wellbores with foamed cements, with similar resolution as for neat cements.
    - Progress toward tool ruggedization for work in adverse conditions.
    - Demonstrated progress toward experimental technique and image processing refinement.
    - Improved detection range through foamed cements (these are more attenuating than neat cements).
    - ***Final success metrics**: Prototype in field functionality similar to the one observed in tests in the laboratory.*

Organization Chart

- Describe project team, organization, and participants.
  - LANL: Develop acoustic source, imaging system, and image processing.
  - NETL: Investigate acoustic metrics for foamed cements. Incorporate new metrics for wellbores in the field.
  - ORNL: Explore different image processing approaches.
  - SNL: Perform experiments in more realistic boreholes. Incorporate data from realistic borehole and compare resolution with lab experiments.

Gantt Chart

Task	Year 1				Year 2				Year 3			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Phase 1 - Feasibility study												
Task 1 – Investigation of existing technology		M2										
Task 2 – Define metrics	M1											
Task 3 – Industry partners/technology maturation plan												
	GoNoGo1											
Phase 2 - Evaluate method on more complex wellbore environments												
Task 1 - Channeling outside casing			M3									
Task 2 - Hardware/software refinement												
Task 3 - Speed-up measurement & analysis												
Task 4 - Method testing on more complex wellbore environments				M4								
Task 5 - Foamed cements manufacturing												
Task 6 - CT of foamed cements												
Task 7 - Acoustics metrics of foamed cements												
Task 8 - Tests on simulated wellbores with foamed cements				M4								
			GoNoGo2									
Phase 3 - Extend method beyond wellbore												
Task 1 - Acoustic source improvement					M5							
Task 2 - Receivers enhancement												
Task 3 - Ruggedized tool							M7					
Task 4 - Image processing refinement						M6						
Task 5 - Technique refinement								M8				
Task 6 - Enhance capabilities for foamed cements												
							GoNoGo3					
							GoNoGo4					
Phase 4 - Technology Development and Verification												
Task 1 - Prototype development									M9			
Task 2 - Prototype verification at lab scale and in field											M11	
Task 3 - Hardware/software enhancement and refinement										M10		

Go/No-Go1 (end Q2Y1)
Tabulate commercial 3D imaging techniques for borehole integrity
- no commercial technologies for high-res 3D imaging technology with similar depth of penetration (~3 m) and resolution (< 5 mm)

Go/NoGo2 (end Y1)
Detect defects at the cement-formation interface, with high resolution- defects detection at the cement-formation interface with a resolution of at least 5 mm

Go/No-Go3 (end Y2)
Tool survival in adverse conditions of corrosiveness, high temperature and high pressure (brines, 250°C, 45 kpsi)
- imaging system can survive in adverse conditions of temperature, pressure and corrosiveness

Go/No-Go4 (end Y2)
Imaging capabilities out in the formation, up to 3 meters
- defects/features (up to ~ 3m) can be resolved in the received signal

Legend shaded areas:
Completed
In work

Bibliography

Peer reviewed publications generated from the project:

- Davis, E.S., Pantea, C., and Sinha, D.N., 2019, Ultrasonic Bessel beam generation from radial modes of piezoelectric discs. Ultrasonics, vol. 96, no. 7, pp. 140-148.
- Chillara, V.K., Davis, E.S., Pantea, C., and Sinha, D.N., 2019, Collimated acoustic beams from radial modes of piezoelectric disc transducers. AIP Conf. Proc., vol. 2102, pp. 040013.
- Chen, Y., Gao, K., Davis, E.S., Sinha, D.N., Pantea, C., and Huang, L., 2018, Full-waveform inversion and least-squares reverse-time migration imaging of collimated ultrasonic-beam data for high-resolution wellbore integrity monitoring. Appl. Phys. Lett., v. 113, issue 7, p. 071903.
- Chillara, V.K., Pantea, C., and Sinha, D.N., 2018, Radial modes of laterally stiffened piezoelectric disc transducers for ultrasonic collimated beam generation. Wave Motion, vol. 76, p. 19-27.
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- Chillara, V.K., Pantea, C., and Sinha, D.N., 2017, Coupled electromechanical modeling of piezoelectric disc transducers for low-frequency ultrasonic collimated beam generation. Proceedings of SPIE, v. 10170, p. 1017024.

- *Pantea, C., Davis, E.S., Chillara, V.K., Greenhall, J., Chavez, A.C., and Sinha, D.N., Development of a Low Frequency Collimated Acoustic Beam for Borehole Integrity Monitoring, Submitted IEEE-TUFFC 2019.*
- *Chavez, A.C., Davis, E.S., Chillara, V.K., and Pantea, C., Development of a 3D Acoustic Borehole Integrity Monitoring System, Submitted IEEE-TUFFC 2019.*
- *Davis, E.S., Chillara, V.K., and Pantea, C., Beam Profile Characterization for Thickness Mode Transducers versus Radial Modes, Submitted IEEE-TUFFC 2019.*
- *Greenhall, J., Chillara, V.K., Sinha, D.N., and Pantea, C., On the bandwidth and beam profile characteristics of a simple low frequency collimated ultrasound beam source. Submitted 2019.*
- *Chillara, V.K., Greenhall, J., and Pantea, C., Ultrasonic waves from radial mode excitation of a piezoelectric disc on the surface of an elastic solid. Submitted 2019.*